

*General Editor*

RAM BALLABH, M. Sc., Ph. D.

*Professor of Mathematics, Lucknow University*

# **BHĀSKARA I AND HIS WORKS**

## **PART II**

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Chapters and verses of the edited text	Whether available in MSS. A and B?	MS. C		Whether com- mented upon in	
		Text ?	Comm. ?	MS. D?	MS. E ?

Verses 48(ii)-78	Yes	Yes	Yes	Yes	Yes
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*Chapter VI*

Verses 1-14(i)	"	"	"	"	"
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Verses 14(ii)-15(i)	No	"	"	"	"
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Verses 15(ii)-18	Yes	"	"	"	"
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Verse 19(i)	"	No	"	"	"
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Verses 19(ii)-25	"	Yes	"	"	"
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Verse 26	"	No	"	"	"
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Verses 27-36(i)	"	Yes	"	"	"
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Verse 36(ii)	"	No	"	"	"
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Verses 37-40	"	Yes	"	"	"
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Verse 41	"	No	"	"	"
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Verses 42-58(i)	"	Yes	"	"	"
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Verses 58(ii)	No	"	"	"	"
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Verses 59-62	Yes	"	"	"	"
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*Chapter VII*

Verses 1-35	"	"	"	"	"
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*Chapter VIII*

Verses 1-22	"	"	"	"	"
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Verses 23-24	"	No	No	"	"
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Verses 25-27	"	Yes	Yes	"	"
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विमर्दाधकलाहीनं यत् स्थित्यर्धं कलामितम्<sup>१</sup> ।  
 तत्कालच्छेद्यकस्तेन भास्वद्विम्बं विखण्डयेत् ॥६६॥<sup>२</sup>  
 प्रदेशस्तस्य<sup>३</sup> बिम्बस्य कर्कटेनावगाह्यते ।  
 पश्चार्धे गृह्यते व्यक्तं पूर्वं चासौ प्रमुच्यते ॥६७॥  
 एवमाशामुखादर्शकलोरुक्लामृतः ।  
 कान्तावदनसंवृत्तवपुषः<sup>४</sup> शशलक्ष्मणः ॥६८॥  
 अपि कार्यो<sup>५</sup> विधिर्ज्यानां विशेषो यः स कथ्यते ।  
 भूच्छायाया गुणाः<sup>६</sup> कल्प्या रवेः कक्ष्यासमुद्भवाः ॥६९॥  
 भागहारः शशाङ्कस्य कर्णं एव प्रकीर्तितः ।  
 शशिवल्लम्बनाल्लब्धं व्यत्ययात् क्षेपशोधने ॥७०॥  
 ताडितो योजनः कर्णो धात्रीव्यासेन<sup>७</sup> भास्वतः ।  
 तयोर्व्यासविशेषेण भूच्छायादैर्घ्यमाप्यते<sup>८</sup> ॥७१॥  
 पञ्चाहृतो रवेः कर्णः षोडशापहृतः<sup>९</sup> फलम् ।  
 भूच्छायादैर्घ्यमाख्यातमिन्दुकर्णस्ततः क्षयः ॥७२॥  
 भूव्यासगुणिते शेषे छायादैर्घ्यं हृते फलम् ।  
 विष्कम्भा<sup>१०</sup>र्धहृतं भक्तं चन्द्रकर्णेन तत्तमः<sup>११</sup> ॥७३॥<sup>१२</sup>  
 अन्ये वदन्ति<sup>१३</sup> शशिनो ग्रहणोपदेशं  
 हीनं गुणैर्दशभिरल्पफलान्तरत्वात्<sup>१४</sup> ।  
 स्थित्यर्धकालमचलं विदधीत तस्मिन्  
 आद्यन्तयोर्ग्रहणमध्यसमुत्थितं यत् ॥७४॥  
 क्षुण्णा<sup>१५</sup> स्थित्यर्धकालेन भुक्तिः षष्ठ्या<sup>१६</sup> समाहृता ।  
 समलिप्ते क्षयः स्पष्टो<sup>१७</sup> मोक्षे क्षेपो निगद्यते ॥७५॥  
 विक्षेपस्तस्य तस्माच्च<sup>१८</sup> स्थित्यर्धं च प्रसंध्यते ।  
 एवं कर्माविशेषोऽयं<sup>१९</sup> विमर्दाधस्य वा पुनः ॥७६॥

<sup>१</sup> कलामृतः A, C; कलामितः B. <sup>२</sup> तत्कालच्छेद्यकं तेन भास्वद्विम्बं विखण्डयेत् A, B. <sup>३</sup> प्रदेशसूत्रं A, B. <sup>४</sup> संवृत्तः वपुषः B. <sup>५</sup> अविकार्यो A, B. <sup>६</sup> भूच्छायायां गुणाः A, B; भू.....छाया रवेः C. <sup>७</sup> धात्रीव्यासेन B. <sup>८</sup> छायादीर्घत्वमाप्यते C. <sup>९</sup> षड्व-  
 शापहृतः C. <sup>१०</sup> तत्ततः A, B. <sup>११</sup> In C the second half of this verse  
 reads as follows विष्कम्भा<sup>१०</sup>र्धहृतं चन्द्रकर्णेन.....तत्तमः <sup>१२</sup> भवन्ति A, B.  
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English Translation  
OF THE  
**MAHĀ-BHĀSKARĪYA**

CHAPTER I

MEAN LONGITUDE OF A PLANET AND PLANETARY  
PULVERISER

Homage to God Śiva :

1. I bow to God Śambhu who bears on His forehead a digit of the Moon illumining all directions by its rays, to Him whose feet are adored by the gods and who is the source of all knowledge.

Homage to planets and stars :

2. Glorious are the rays of the Sun which make the lotus blossom forth, (and those) of the Moon whose beauty is like that of the damsel's face, (as also are) the long and clear rays of the stars including Jupiter; so also is the lustre of Mars, Mercury, Saturn, and Venus.

A benedictory stanza in appreciation of the *Āryabhaṭīya* and the pupils of Āryabhaṭa I :

3. May the accurate *Āśmaka-tantra* (*āśmakam sphuṭa-tantram*), which has been acquired by penance, live long in the world for its excellent qualities. May also the pupils of (Ārya)-bhaṭa, who are free from sins and have conquered the enemies of passions, live long.

The *āśmakam sphuṭa-tantram* ("the accurate *Āśmaka-tantra*"), according to the commentators Govinda Svāmī and Parameśvara, is the *Āryabhaṭīya* of Āryabhaṭa I (born 476 A.D.). Govinda Svāmī writes :

"By this (stanza) the author exhibits the greatness of the *Āryabhaṭīya*, ..."

So also has said Parameśvara :

"*tapobhiḥ* etc. is a benediction on the *Āryabhaṭa-tantra* and the pupils of Āryabhaṭa."

Exclusive references to Āryabhaṭa I and his work at several places in the present work and the name *Āryabhaṭa-karma-nibandha* ("a compen-

dium of the astronomical processes taught by Āryabhaṭa") given to this work by the author<sup>1</sup> indeed show that *āśmakam sphuṭa-tantram* is none else than the *Āryabhaṭīya*.

The word *āśmaka* (*āśmaka+an*) literally means "pertaining to Āśmaka", and likewise *āśmakam sphuṭa-tantram* means "an accurate work on astronomy written, studied, or venerated in Āśmaka, or belonging to Āśmaka". This seems to suggest that Āryabhaṭa I, the author of that work, belonged to the Āśmaka country.<sup>2</sup> It is noteworthy in this connection that according to Nīlakaṇṭha (1500 A.D.) he was born in that country.<sup>3</sup>

Reference to the *Āryabhaṭīya* in the above stanza at the beginning of this work is meant, as stated in the *Prayoga-racanā* and by Govinda Svāmī to indicate the school to which the present work belongs.

### MEAN LONGITUDE OF A PLANET

A rule for calculating the *ahargana* :

4-6. Add 3179 to the number of elapsed years of Śaka kings; then multiply (that sum) by 12; and then add the number of months elapsed (since the beginning of Caitra). Put down the result at two places. At one place multiply (that) by the number of intercalary months in a *yuga* and divide by the number of solar months in a *yuga*; and add the resulting intercalary months (omitting the fraction of a month) to the result put at the other place. Multiply the sum by 30 and then add the number of lunar days (*tithis*) elapsed (since the beginning of the current month). Set down the result (i.e., the sum obtained) at two places. At one place multiply that by the number of omitted lunar days (in a *yuga*) and divide by the number of lunar days (in a *yuga*), and subtract the resulting omitted lunar days (neglecting the fraction of a day) from the result set down at the other place. The result (thus obtained) is the number of (mean) civil days elapsed since the beginning of Kali-yuga (at mean sunrise at Lankā on the given lunar day). These

<sup>1</sup> See vs. 26 of Chapter VIII.

<sup>2</sup> For the Āśmaka country, see Part I, Chapter 2.

<sup>3</sup> See Nīlakaṇṭha's comm. on *Ā*, ii, 1.

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Mutually dividing 36641 and 394479375, we have

$$\begin{array}{r} 36641 \mid 394479375 \text{ (10766} \\ 394477006 \end{array}$$

$$\begin{array}{r} 2369 \mid 36641 \text{ (15} \\ 35535 \end{array}$$

$$\begin{array}{r} 1106 \mid 2369 \text{ (2} \\ 2212 \end{array}$$

$$\begin{array}{r} 157 \mid 1106 \text{ (7} \\ 1099 \end{array}$$

$$\begin{array}{r} 7 \mid 157 \text{ (22} \\ 154 \end{array}$$

$$\begin{array}{r} 3 \mid 7 \text{ (2} \\ 6 \end{array}$$

$$1 \times 27 - 24 = 3 \text{ (1}$$

$$3$$

$$0$$

We have chosen here the number 27 as the optional number (*mati*).<sup>1</sup>

Writing down the quotients one below the other as prescribed in the rule, we get the chain

$$\begin{array}{r} 10766 \\ 15 \\ 2 \\ 7 \\ 22 \\ 2 \\ (mati) \ 27 \\ 1 \end{array}$$

<sup>1</sup> The *mati* may be chosen at any stage after an even number of quotients are obtained.

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*ahargana* calculated (for the given day) gives the *ahargana* for the required day<sup>1</sup>.

This rule will become clear by the following solved example.

Example. "The mean longitude of the Sun (for sunrise) on a Wednesday is stated to be 8 signs, 25 degrees, 36 minutes, and 10 seconds. Say correctly after how much time (since the beginning of Kaliyuga) will the Sun again assume the same position (at sunrise) on a Thursday, Friday, and Wednesday."<sup>2</sup>

We first determine the *ahargana* elapsed at sunrise on Wednesday when the Sun's mean longitude is 8 signs, 25 degrees, 36 minutes, and 10 seconds.

$$\begin{aligned}\text{Since the Sun's mean longitude} &= 8 \text{ signs } 25^\circ 36' 10'' \\ &= 956170'',\end{aligned}$$

therefore, by stanza 46(ii), the residue of revolutions = 155222.

Thus we have to solve the pulveriser

$$\frac{576x - 155222}{210389} = y,$$

where  $x$  is the *ahargana* and  $y$  the revolutions performed by the Sun.

Solving this equation, we obtain

$$\begin{aligned}x &= 1000, \\ y &= 2.\end{aligned}$$

Hence the *ahargana* for the given Wednesday = 1000.

(i) Now we find out the *ahargana* elapsed at sunrise on a Thursday when the Sun again occupies the same position.

Let the required *ahargana* be  $1000 + A$ . Then in  $A$  days the Sun will describe complete revolutions. Also since Thursday is in advance of

<sup>1</sup> The text is a little obscure at this place. Our translation is based on the interpretations given by the commentators. It also agrees with the details of the rule supplied by the author Bhāskara I himself in his commentary on  $\bar{A}$ , ii. 32-33.

<sup>2</sup> Bhāskara I's example occurring in his comm. on  $\bar{A}$ , ii. 32-33.

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Misitapurī and Taparṇī, too, remain unidentified. Śaṅkaranārāyaṇa in his commentary on the *Laghu-Bhāskarīya*<sup>1</sup> pronounces Misitapura as Nisitapura, so it is difficult to say which pronunciation is correct.

The Sitavara mountain ("the excellent white mountain") is the Śvetaśaila of Lalla, the Sitādri of Śrīpati, and the Sitaparvata of Bhāskara II. According to Śrīpati, it is the seat of the six-faced god Svāmikārtikeya. It can therefore be identified with Krauñca-giri or Kumāra-parvata, situated at a distance of 3 *yojanas* from Śrīśaila.<sup>2</sup>

Vātsyagulma is the town of Vatsarāja Udayana, usually called Vatsapattana. It has been identified with Kauśāmbī (modern Kosam) situated on the river Jumna at a distance of about 38 miles from Allahabad.

Vananagarī<sup>3</sup> is probably Tumba-vana-nagara (modern Tumain) in Madhya Bhārata. Avantī is modern Ujjain. Sthāneśa is Sthāneśvara, a place in Kurukṣetra. Meru is the north pole.

From the above identification we find that the places mentioned in the text do not lie precisely on one meridian. The places mentioned by other astronomers also do not satisfy this requirement. It has not been possible to give any satisfactory explanation to this discrepancy. Probably the geographical knowledge of ancient Hindu writers was not sound in respect of places other than their own.

We give below the lists of places lying on the Hindu prime meridian according to other Hindu astronomers which will be useful for comparison and reference.

(i) **Lalla's list.**<sup>4</sup> Laṅkā, Kumārī, Kāñcī(varam), Pārṇātā, Kṛṣṇā (the river), Śvetaśaila ("the white mountain"), Vātsyagulma, Ujjayinī, Gargarāt, Āśraya (? Āśrama), Mālvānagara, Cāyūśiva (?), Rohitaka (Rohtak), Kurukṣetra (the battle field of the Bhārata War), Himavān (the Himalayas), and Meru.

<sup>1</sup> i. 23.

<sup>2</sup> See *Kalyāṇa, Tīrthāṅka*, pp. 310 and 330.

<sup>3</sup> In case the correct reading is Varanagarī, it may be identified with Barnagar.

<sup>4</sup> Mentioned in Āmarāja's comm. on *KK*, i. 13.

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by him have been supplied by his commentator Prthūdaka Svāmi (860 A.D.)<sup>1</sup> The method of getting the correct east-west line is found to occur also in the *Siddhānta-śekhara*<sup>2</sup> of Śrīpati (c. 1039 A.D.) the *Śiddhānta-śiromaṇi*<sup>3</sup> of Bhāskara II (1150 A.D.) etc. For practical purposes, however, the method given in the text is good enough.

An alternative rule :

3. With the three points (at the ends of the three shadows of the gnomon) corresponding to (any three) different times (in the day), draw two fish-figures (each with two of the three points) in accordance with the usual method. From the point of intersection<sup>4</sup> of the lines passing through the mouth and tail (of the two fish-figures), determine the north and south directions.<sup>5</sup>

According to this rule, the north-south line is the one joining the foot of the gnomon with the point of intersection of the mouth-tail lines of the two fish-figures.

Varāhamihira states this rule as follows :

“Mark three times, from the centre, the end of the gnomon’s shadow, and then describe two fish-figures. Thereupon describe a circle, taking for radius a string, that is fastened to the point in which the two strings issuing from the heads of the fish-figures intersect, and that is so long as to reach the three points marked. On the given day the shadow of the gnomon moves in that circle, without departing from it.

“The line joining the centre of that circle and the base of the gnomon is the south-north line ; and the interval in north direction (between that circle and the gnomon) is the midday shadow.”<sup>6</sup>

<sup>1</sup> See Sudhākara Dvivedī’s comm. on *BrSpSi*, iii. 1.

<sup>2</sup> iv. 14-16.

<sup>3</sup> I, iii. 8.

<sup>4</sup> This point of intersection is the same as the centre of the circle passing through the three shadow-ends.

<sup>5</sup> This rule is found also in *PSi*, xiv. 14-16 ; *BrSpSi*, iii. 2 ; *ŚiDVṛ*, I, iii. 2 ; and *ŚiŚe*, iv. 4.

<sup>6</sup> See G. Thibaut and S. Dvivedī, *The Pañca-siddhāntikā*, Banaras (1889), xiv, 14-16, English translation, p. 79.



Brahmagupta is more precise. He says :

"The point where the lines passing through the two fish-figures, which are drawn by means of three shadow-ends (of the gnomon), intersect each other is, for places in the northern hemisphere, the south direction<sup>1</sup> (if the midday shadow falls to the north of the foot of the gnomon). If the midday shadow falls towards the south of the foot of the gnomon, it is the north direction".<sup>2</sup>

The above rule is evidently based on the assumption that the locus of the end of the shadow of the gnomon is a circle. In fact, for places whose latitudes are less than  $90^\circ - \varphi$  (where  $\varphi$  is the obliquity of the ecliptic), this locus is a hyperbola, so the above assumption is not a correct one. The above rule will, however, give an approximately correct result if the three shadow-ends chosen are not far removed from the vertex of the hyperbola.

The method of drawing a circle through three given points by the aid of two fish-figures is called "*triśarkarā-vidhāna*" by Bhāskara I.<sup>3</sup>

A rule for getting the length of the hypotenuse of the shadow :

4. The square root of the sum of the squares of the gnomon and its shadow (is equal to the hypotenuse of the shadow : this), say the learned (astronomers), is always the semi-diameter of its own circle in the calculations with the shadow.<sup>4</sup>

By "the semi-diameter of its own circle" is meant "the semi-diameter of the circle of shadow".

The circle of shadow is, as Bhāskara I has said<sup>5</sup>, useful in the application of proportion in connection with the problems involving the shadow of the gnomon. For example, in finding out the Rsine<sup>6</sup> of the Sun's zenith distance from the shadow of the gnomon, the proportion is :

<sup>1</sup> The north direction being indicated by the end of the midday shadow of the gnomon.

<sup>2</sup> *BrSpSi*, iii. 2.

<sup>3</sup> See *LBh*, vi. 16.

<sup>4</sup> This rule is found also in *Ā*, ii. 14.

<sup>5</sup> In his commentary on *Ā*, ii. 14.

<sup>6</sup> Rsine stands for "radius  $\times$  sine".

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In fact, however, the rays coming from the Sun are not exactly parallel, so that the angle between the gnomon and the Sun's ray reaching the ground through the upper end of the gnomon is not exactly equal to the zenith distance of the Sun. Moreover, the shadow which is actually measured is the umbra (i.e., the shadow between the foot of the gnomon and the point where the ray coming from the uppermost point of the Sun's disc and passing through the upper end of the gnomon meets the ground) and not the theoretical shadow corresponding to the central ray of the Sun coming through the upper end of the gnomon. Later Hindu astronomers have, therefore, prescribed corrections to the results determined according to the rules in the above stanza.<sup>1</sup>

For practical purposes the rules stated above are good enough. The error is negligible.

Rules for determining the declination, day-radius, earthsine, and ascensional difference (for the Sun or a point on the ecliptic):

6-7. Multiply the Rsine of the given longitude by 1397 and always divide by the radius; the result is the Rsine of the declination for that time. Subtract the square of that (Rsine of the declination) from the square of the radius and then take the square root (of the difference); the result is called the day-radius.<sup>2</sup> Multiply the Rsine of the latitude by (the Rsine of) the given declination and divide by (the Rsine of) the colatitude: the result is the earthsine.<sup>3</sup> Multiply the earthsine by the radius and then divide (the product) by the day-radius; then reduce (the resulting Rsine) to arc. Whatever (arc) is thus obtained is termed "the ascensional difference" by the best amongst the good (astronomers).<sup>4</sup>

<sup>1</sup> These corrections occur in *KPr*, iv. 2; *KP*, viii. 3; and *TS*, iii. 10(ii)-11.

<sup>2</sup> This rule is found also in *S Si*, ii. 28; *BrSpSi*, ii. 55; *LBh*, ii. 16; *SiDV<sub>r</sub>*, I, ii. 17; *SiSe*, iii. 63-64; *SiSi*, I, ii. 47(ii).

<sup>3</sup> This rule is found also in *A*, iv. 24; *BrSpSi*, ii. 56; *LBh*, ii. 17; *SiDV<sub>r</sub>*, I, ii. 18; *SiSe*, iii. 66; *SiSi*, I, ii. 48.

<sup>4</sup> This rule is found also in *A*, iv. 26; *LBh*, ii. 17-18; *SiSe*, iii. 65.

<sup>5</sup> This rule is found also in *SuSi*, ii. 61; *BrSpSi*, ii. 57-58; *LBh*, ii. 18; *SiDV<sub>r</sub>*, I, ii. 18; *SiSe*, iii. 67 (i); *SiSi*, I, ii. 49 (i).

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Fig. 12 is a reproduction of the previous figure. As in the previous figure, M is the mean Sun and T the true Sun. ET is the true distance of the Sun. The above rule relates to the determination of ET. The method used is the method of successive approximations.

In the triangle ESD, where SD is parallel to EU, we have

$$ES = R,$$

and  $SD = T_1M$ , the radius of the Sun's mean epicycle.

If the value of  $TM$ , the radius of the Sun's true epicycle, were known, the Sun's true distance ET could be easily derived from a comparison of the similar triangles ESD and ETM. But the value of  $TM$  is unknown and is itself dependent on that of ET. Hence the necessity of the method of successive approximations (*usakṛtkarma*).

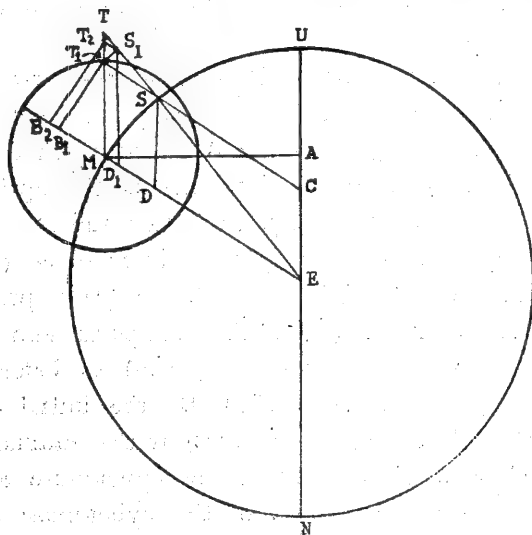


Fig. 12

With centre E and radius  $ET_1$  draw an arc of a circle cutting ET at  $S_1$ ; through  $S_1$  draw a line  $S_1D_1$  parallel to EU and a line  $S_1T_1$  parallel to EM meeting  $MT_1$  produced at  $T_2$ ; and from  $T_2$  draw a line  $T_2B_2$  perpendicular to EM produced. Again with centre E and radius  $ET_2$  draw an arc of a circle cutting ET at  $S_2$ ; through  $S_2$  draw a line  $S_2D_2$  parallel to EU and a line  $S_2T_2$  parallel to EM meeting  $MT_1$  produced at  $T_3$ ; and from  $T_3$  draw a line  $T_3B_3$  perpendicular to EM produced. Continue this process successively. The sequence of points  $S_1, S_2, S_3, \dots$  and also that of points  $T_1, T_2,$

$T_3, \dots$  will converge to  $T$ . This is the basis of the method used. The details are as follows:

$MT_1$  is taken as the first approximation  $r_1$  to the radius of the Sun's true epicycle and likewise  $ES_1$ , which is equal to<sup>1</sup>

$$\sqrt{(R + koṭiphala)^2 + (bāhuphala)^2},$$

is taken as the first approximation  $H_1$  to the Sun's true distance.<sup>2</sup>

Now from the similar triangles  $S_1D_1E$  and  $SDE$ ,

$$S_1D_1 = \frac{SD \times H_1}{R} = \frac{r_1 \times H_1}{R}.$$

But  $MT_2 = S_1D_1$ . Therefore,

$$MT_2 = \frac{r_1 \times H_1}{R}. \quad (1)$$

Again from the similar triangles  $T_2B_2M$  and  $MAE$ , we have

$$\begin{aligned} T_2B_2 &= \frac{MA \times T_2M}{R} \\ &= \frac{MA \times r_1}{R} \cdot \frac{H_1}{R} \\ &= \frac{bāhuphala \times H_1}{R}. \end{aligned} \quad (2)$$

$$\text{Similarly, } B_2M = \frac{koṭiphala \times H_1}{R}. \quad (3)$$

Therefore,

$$ET_2 = \sqrt{(R + MB_2)^2 + T_2B_2^2},$$

where  $MB_2$  and  $T_2B_2$  are given by (3) and (2) respectively.

$MT_2$  is taken as the second approximation  $r_2$  to the radius of the Sun's true epicycle and likewise  $ES_2 (=ET_2)$  is taken as the second approximation  $H_2$  to the Sun's true distance.

Since  $H_1 > R$ , therefore from (1)

$$r_2 > r_1;$$

and consequently,

$$H_2 > H_1.$$

<sup>1</sup> For,  $ES_1 = ET_1$ ; and from the right-angled triangle  $T_1B_1E$ , we have

$$ET_1^2 = EB_1^2 + B_1T_1^2 = (EM + MB_1)^2 + B_1T_1^2,$$

where  $EM = R$ ,  $MB_1$  is the *koṭiphala* and  $B_1T_1$  is the *bāhuphala*.

<sup>2</sup> In the right-angled triangle  $EB_1T_1$ ,  $B_1T_1$  is called the base,  $EB_1$  is called the upright, and  $ET_1$  is called the hypotenuse.

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The author takes up now the Hindu eccentric theory. Here the mean Sun (or Moon) is supposed to move on a circle centred at the earth called the concentric (*kakṣāvṛtta*), whereas the true Sun (or Moon) is supposed to move on another equal circle called the eccentric (*pratimaṇḍala*) with the same angular velocity as the mean Sun (or Moon) has. The centre of the eccentric is supposed to be deviated from the Earth towards the Sun's (or Moon's) apogee by an amount equal to the Rsine of the Sun's (or Moon's) greatest equation of the centre.

In Fig. 13, the circle UMN<sub>1</sub>Y centred at E, the Earth, is the concentric and the circle U<sub>1</sub>T<sub>1</sub>L centred at C is the eccentric for the Sun. When the mean Sun is at U, the true Sun is at U<sub>1</sub> (the apogee). Subsequently, when the mean Sun is at M, the true Sun is at T<sub>1</sub>. Since the mean Sun and the true Sun have the same angular velocity relative to the apogee, the line MT<sub>1</sub> will always be parallel to the apse line EU.

Let XY be perpendicular to EU through E, and T<sub>1</sub>B perpendicular to XY. Then in the triangle T<sub>1</sub>BE, right-angled at B, we have

$BE = MA = R \sin (\text{arc } MU)$ ,  
and  $T_1B = T_1M + MB = EC + R \sin (\text{arc } MX)$ ,  
where the arc MX is the *koṭi* and EC is the Rsine of the greatest equation of the centre for the Sun.

Had the length EC been equal to the radius of the Sun's true epicycle for the mean sun at M, T<sub>1</sub>E would have been the Sun's true distance, but EC corresponds to the radius of the Sun's tabulated epicycle, which is mean and not true, therefore T<sub>1</sub> is not the true position of the Sun and likewise T<sub>1</sub>E is not the true distance of the Sun. The true distance is determined as follows:

Join T<sub>1</sub>C and let it intersect the concentric at S. Produce MT<sub>1</sub> and ES to meet at T. Then MT denotes the true distance between the centres of the concentric and the eccentric, T the position of the true Sun, and ET the true distance of the sun.

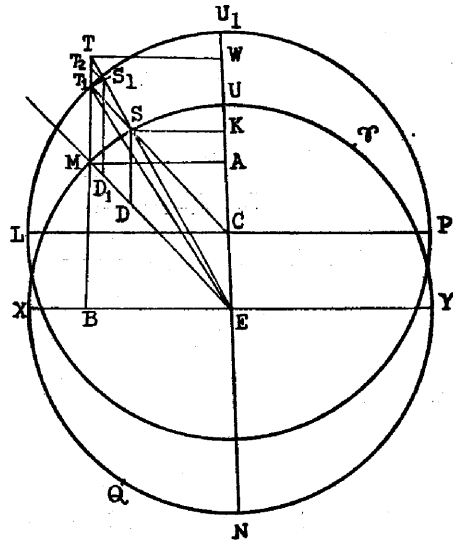


Fig.13 .



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We explain below the motion of the planets, Mars, Mercury, Jupiter Venus, and Saturn, according to the Hindu epicyclic theory.

Consider Fig. 14. E is the Earth. The bigger circle USM centred at E is the deferent (*kakṣāvṛtta*). The point U on the deferent is the planet's *mandocca* (apogee). M is the position of the mean planet which is supposed to move on the deferent with mean velocity from west to east (in the anticlockwise direction indicated by an arrow). The small circle centred at M is the planet's *manda* epicycle corresponding to the position M of the mean planet: this *manda* epicycle is determined as taught in stanzas 38-39(i). EC is equal to  $MM_1$ ,  $M_1$  and C are joined by a line which intersects the deferent at the point S.  $MM_1$  and ES are produced to meet at the point T'. This point T' is, according to the Hindu astronomers, the position of the true-mean planet. The so called true-mean planet is assumed to move on the periphery of the true epicycle of radius  $MT'$  centred at M with the same velocity as the mean planet has relative to the apogee but in the opposite sense (i.e., clockwise). The point S denotes the position of the true-mean planet on the deferent.

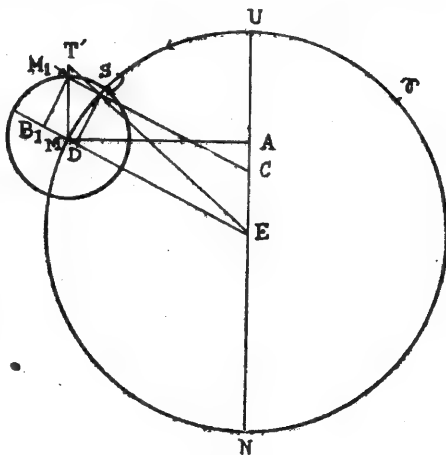


Fig. 14

sum or difference as the correct longitude of the planet's *mandocca*. Therefrom calculate the arc corresponding to the planet's *mandakendraphala* and apply that to the planet's mean longitude. Thus is obtained the planet's true-mean longitude. Then calculate the arc derived from the planet's *śighrakendraphala* and apply that to the true-mean longitude of the planet. Then is obtained the true longitude of the planet (Mercury or Venus).

The rule stated in stanza 44 occurs also in *Ā*, iii. 24; *LBh*, ii. 37-38; and *ŚiDV*, I, ii. 35. The method prescribed here for finding the true longitudes of Mercury and Venus has been prescribed for all the planets in the *Karaṇa-prakāśa* (ii (b). 3, 4), the *Graha-lāghava* (iii. 10), the *Ravi-siddhānta-mañjarī* (ii. 1), and the *Karaṇa-kaustubha* (iii. 19), etc., all of them being calendrical works,

If  $\Upsilon$  be the first point of Aries, then  $\angle ME\Upsilon$  (or arc  $MU\Upsilon$ ) is the mean longitude of the planet, and  $\angle SE\Upsilon$  (or arc  $SU\Upsilon$ ) is the true-mean longitude of the planet. The arc MS by which the true-mean longitude of the planet differs from the mean longitude of the planet is obtained as follows:

Let MA be the perpendicular from M on EU,  $M_1B_1$  and SD the perpendiculars from  $M_1$  and S on EM. Then comparing the triangles  $M_1B_1M$  and MAE, we have

$$\begin{aligned} M_1B_1, \text{ i.e., } SD &= \frac{MA \times MM_1}{EM} \\ &= \frac{R \sin (\text{bāhu due to } \textit{mandakendra}) \times (\text{radius of corrected } \textit{manda} \text{ epicycle})}{R} \\ &= \frac{(\text{corrected } \textit{manda} \text{ epicycle}) \times R \sin \theta}{80}, \end{aligned} \quad (1)$$

where  $\theta$  denotes the *bāhu* due to *mandakendra*.<sup>1</sup>

Reducing the right-hand side of (1) to the corresponding arc, we get the arc MS.

This arc MS has been referred to by Bhāskara 1 as the arc corresponding to the *mandakendraphala*, because it corresponds to  $M_1B_1$  which denotes the *mandakendraphala*. Generally it is known as *mandaphala*. It is subtracted from or added to the mean longitude of the planet, according as the *mandakendra* is less than or greater than  $180^\circ$ , as in the case of the Sun and Moon.<sup>2</sup> Thus

true-mean longitude = mean longitude  $\mp$  *mandaphala*,  
according as the *mandakendra* is less than or greater than  $180^\circ$ .

Now consider Fig. 15. Here also E is the Earth and the bigger circle centred at E is the deferent (*kakādvṛtta*); U is the planet's *mandocca* ("apogee") and V the planet's *sihrocca*. S is the position of the true-mean planet on the deferent. The small circle centred at S is the planet's *sihgra* epicycle: it is derived as taught in stanzas 38-39(i). ST is drawn parallel to EV. Then T denotes the position of the true planet. ET is called the *sihgrakarṇa*.

<sup>1</sup> The *bāhu* due to *mandakendra* is derived in the same way as in the case of the Sun. The corrected *manda* epicycle used in this last result is that divided by 41.

<sup>2</sup> It may be pointed out that in the case of the Sun and Moon the *mandaphala* is the equation of the centre, called *bāhuphala* by Bhāskara 1.



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To the longitude of the *mandocca* ("apogee"), apply (the *spaṣṭa-bhuja* due to the *mandakendra*, as a positive correction) in the manner prescribed above (in stanza 22). From the longitude of the *śighrocca* subtract the *spaṣṭa-bhuja* (due to the *śighrakendra*) (as follows) :

(When the *śighrakendra* is) in the first and second quadrants, subtract from the longitude of the *śighrocca* the *spaṣṭa-bhuja* itself and that subtracted from half a circle (i.e.,  $180^\circ$ ) respectively; (when the *śighrakendra* is) in the remaining quadrants (i.e., third and fourth), subtract that (*spaṣṭa-bhuja*) as increased by half a circle and that (*spaṣṭa-bhuja*) subtracted from a circle respectively.

In Fig. 16, let the circle UMN centred at E, the Earth, be the concyclic (*kakṣāvṛtta*), the circle centred at C the *manda* eccentric (*mandapratiṛtta*), U the planet's *mandocca* (apogee), and M the mean position of the planet. Let  $MM_1$  be parallel to EU; and let S be the point where  $CM_1$  intersects the concyclic, and T' the point where  $MM_1$  and ES produced meet. Then T' is the position of the true-mean planet and S the position of the true-mean planet on the concyclic. If  $\Upsilon$  be the first point of Aries, then

arc  $\Upsilon US$  is the true-mean longitude of the planet.

When the mean planet is in the first quadrant beginning with U, as shown in the figure,

arc  $\Upsilon US = \Upsilon U + US$ ,  
i. e., true-mean longitude  
= longitude of the planet's  
apogee + *spaṣṭa-bhuja*.<sup>1</sup>

When the mean planet is in the second anomalistic quadrant, the *spaṣṭa-bhuja* is the arcual distance of the true-mean planet from the perigee M. Thus, in this case

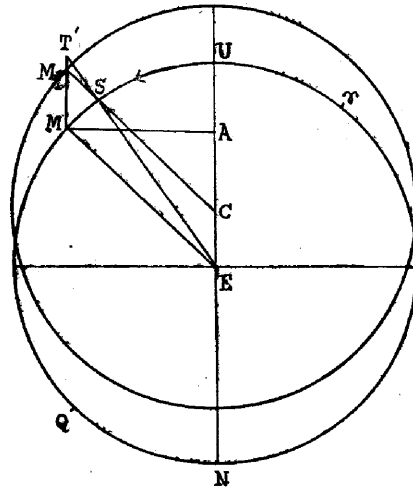


Fig. 16

<sup>1</sup> As in the case of the Sun, arc MU is the *bāhu* or *bhuja* (due to planet's *mandakendra*) and arc SU is the *spaṣṭa-bhuja*.

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for (sunrise on) the day elapsed (i.e., yesterday) is the (true) daily motion (of the planet for the day elapsed).

Hindu astronomers have recognised eight kinds of motion of the planets. According to the *Sūrya-siddhānta*,<sup>1</sup> these are: (1) *vakra* (beginning of regression), (2) *ativakra* (maximum regression), (3) *kuṭila* (end of regression and beginning of direct motion), (4) *manda* (slow), (5) *mandatara* (slower), (6) *sama* (mean), (7) *śighra* (fast), and (8) *śighratara* (faster). Of these, says the author of the *Sūrya-siddhānta*, the first three are the different kinds of retrograde motion and the last five the various forms of direct motion.<sup>2</sup> The above stanzas 56 and 57 deal with the three varieties of retrograde motion. The details of the five varieties of direct motion are given by Śrīpati in his *Siddhānta-śekhara*.<sup>3</sup> According to him, the motion is said to be "very fast", when the planet (measured from its *śighrocca*) is in the beginning of the sign Aries or Pisces; "fast", when in the beginning of Taurus or Aquarius; "mean" when in the beginning of Gemini or Capricorn; "slow", when in the first half of Cancer or in the last half of Sagittarius; and "very slow", when in the first half of Sagittarius or in the last half of Cancer.

The following table gives the *śighrakendras* of the planets when they take up retrograde motion according to various Hindu authorities:

**Śighrakendras of the planets when they take up retrograde motion.**

Planet	Śighrakendra				
	<i>BrSpSi</i> (ii.48), <i>SiDV<sub>r</sub></i> (I.ii. 47), <i>KPr</i> (iii. 8), <i>SiSe</i> (iii. 58), <i>SiSi</i> (I, ii. 41)	<i>KKau</i> (ii.23), <i>GLā</i> (iii.15)	<i>MSi</i> (iii.31)	<i>VVS<sub>i</sub></i> (ii.30), <i>SūSi</i> (ii.53-54)	<i>PiSi</i> , <i>KK</i> (iii. 8-17)
Mars	163°	163°	163°	164°	164°
Mercury	145°	145°	145°	144°	146°
Jupiter	125°	125°	125°	130°	125°
Venus	165°	167°	166°	163°	165°
Saturn	113°	113°	113°	115°	133°

<sup>1</sup> ii. 12. <sup>2</sup> *SūSi*, ii.13. <sup>3</sup> iii. 60.



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of the Rsine of the zenith distance of the Moon for that time are prescribed to be made with the setting point of the ecliptic (taken for the Sun).

The only difference in this case is that the time to elapse before moonset, instead of being found out from the *asus* intervening between the Moon and the Sun (as was done in the previous case), should be found out in this case from the *asus* intervening between the Moon and the setting point of the ecliptic, or, as the commentator Paramesvara says, from the *asus* intervening between the rising point of the ecliptic and the point six signs in advance of the Moon. The *asus* correspond to oblique ascension as in the previous case.

Representation of the elevation of the lunar horns in the second quarter of the month :

19. (When the calculation relating to the elevation of the Moon's horns is made) after the eighth lunar day, the rising point of the ecliptic itself should be regarded as the Sun. And under that assumption should be made the calculation of the Rsine of the Moon's altitude, etc., with the exception of the calculation of the measure of the illuminated part (of the Moon's disc).

A rule for the determination of the Rsine of the Moon's altitude to be used in connection with the elevation of the lunar horns :

20. The Rsine of the Moon's altitude should be calculated from the *asus* intervening between the Sun and the Moon, or between the rising or setting point of the ecliptic and the Moon subject to the time of calculation, the *asus* being those obtained by applying the rule once and not successively.

A rule telling that the above calculations pertaining to the elevation of the lunar horns relate to the first half of the month only :

21. In this manner, at sunset or any other time, with the help of the longitudes of the Sun, Moon and the Moon's ascending node, should be made this calculation relating to the Moon till the fifteenth lunar day: so has been said.

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<sup>2</sup> Bhāskara I, the author of the *Mahā-Bhāskariya*, was a different person from his namesake of the twelfth century A. D., the author of the *Siddhānta-śiromaṇi* and *Līlāvati*, etc. He lived in the seventh century of the Christian era and was a contemporary of Brahmagupta (628 A. D.). He wrote three works on astronomy which were composed in the following order: (1) the *Mahā-Bhāskariya*, (2) a commentary on the *Āryabhaṭīya*, and (3) the *Laghu-Bhāskariya*. His commentary on the *Āryabhaṭīya* was written in 629 A. D., i. e., one year after the completion of the *Brāhma-sphuṭa-siddhānta* of Brahmagupta.

Bhāskara I was a follower of Āryabhaṭa I, the author of the *Āryabhaṭīya*. His works provide us with a detailed exposition of the astronomical methods taught by Āryabhaṭa I and throw light on the development of astronomy during the sixth and early seventh century A. D. in India. For details regarding the life and works of Bhāskara I, the reader is referred to Part I of the present work.



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# BHĀSKARA I AND HIS WORKS

## PART II

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# MAHĀ-BHĀSKARĪYA

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